

**IN THE SPECIFICATION**

Please amend page 1 by inserting the following heading between the title of the invention and the first paragraph:

**“FIELD OF THE INVENTION”**

Please amend page 1 by inserting the following heading between the first and second paragraphs:

**“BACKGROUND OF THE INVENTION”**

Please amend page 5 by inserting the following heading on line 28:

**“BRIEF SUMMARY OF THE INVENTION”**

Please amend page 11 by inserting the following on line 18:

**“BRIEF DESCRIPTION OF THE DRAWINGS”**

Please amend page 12 by inserting the following heading on line 3:

**“DETAILED DESCRIPTION OF THE INVENTION”**

Please amend page 16 by inserting the following language between the “CLAIMS” heading and claim 1:

**“We claim:”**

Please amend page 15 by adding the following text beginning on line 17 as follows:

“In use the cell is used in conjunction with a device for measuring the electrical characteristics of the cell. For example, but without limitation, the device may be configured to measure the electrical current (in an amperometric configuration) or the emf (in a potentiometric configuration) produced across the cell.

Each electrode may be comprised from, or coated with, its respective catalyst. The "catalyst" electrode materials may be a metal, a conducting oxide or another suitable catalysing material. The selection of the electrode material will favour the dissociation of the species of

interest whilst minimising the dissociation for permanent (ie not of interest) species. The skilled addressee will no doubt envisage appropriate catalysts for separating certain ionic species from certain molecules without departing from the invention. Without limitation, catalysts may include platinum (for liberating  $H^+$  from water or  $O^{2-}$  from molecular oxygen), ruthenium (for liberating  $H^+$  from hydrocarbons), nickel, gold, silver or silver salts.

During use of the sensor, a reference environment with known quantities of the species is provided within the reference environment space. This is used as a reference with which the measured quantity of the species in the monitored environment contained in the monitored environment space can be compared. By applying a suitable algorithm incorporating measured parameters of the electrical signal generated by the cell and known characteristics of the reference environment, the partial pressure, and thus relative quantity of the species in the monitored environment can be calculated.

In circumstances where it would be relatively straightforward to provide a reference environment which contains, as the reference molecule, a known quantity of the same chemical species as the contaminant molecule, for example,  $O_2$ , the catalyst for the measurement electrode may conveniently comprise the same material as the catalyst for the reference electrode. However, where it would be relatively difficult to provide such a reference environment, for example, where the contaminant molecule is  $H_2O$ , depending on the chosen reference molecule the catalyst for the measurement electrode may comprise different material from the catalyst for the reference electrode. Even in this latter situation, the catalysts may still comprise the same material, for example platinum would be a suitable catalyst for the dissociation of  $H_2O$  as a contaminant molecule and for the dissociation of  $H_2$  as a reference molecule.

The reference environment space may be a sealed enclosure into which a controlled environment is provided. The source of ionic species provided in the reference environment may be a source of the contaminant molecule or any other source of that ionic species. The source may be provided in any physical phase, for example, but not limited to a gas, a liquid or a solid. For ease of storage and handling, a solid-state source is preferable. Suitable solid-state sources will no doubt occur to the skilled addressee. Examples of suitable reference environment sources include but are not strictly limited to a gas, a metal, a

metal/metal-hydride, a metal alloy/metal-hydride, any solid hydrated species, any solid organic species (for  $H^+$ ) or copper/copper oxide ( $Cu_2O$ ), nickel/nickel oxide ( $NiO$ ) and chromium/chromium oxide ( $Cr_2O_3$ ) (for  $O^{2-}$ ).

Other suitable sources may include but are not limited to organic acids or liquid organic species (for  $H^+$ ).

The means for initiating the catalysis of the dissociation of the molecules preferably comprises means for controlling and monitoring the temperature of the cell. In the preferred embodiments, sealing means are provided for separating a reference environment space from a monitored environment space, the means for controlling the temperature of the cell including a heating device contained within the reference environment space. Thus, in a second aspect the present invention provides a contaminant molecule sensor configured for use in a vacuum environment, the sensor comprising an electrochemical cell comprising a measurement electrode coated with, or comprised from, a catalyst selected for its ability to catalyse the dissociation of a contaminant molecule into its ionic species, a reference electrode coated with, or comprised from, a catalyst selected for its ability to catalyse the dissociation of a reference molecule into its ionic species, and a solid-state ionic species conductor bridging the measurement electrode and the reference electrode, the conductor being selected to conduct an ionic species common to the dissociated contaminant and reference molecules, means for controlling and monitoring the temperature of the cell, and sealing means for separating a reference environment space from a monitored environment space, the means for controlling and monitoring the temperature of the cell including a heating device contained within the reference environment space

The means for controlling and monitoring the temperature may include an electrically powered heater, for example a nichrome wire wound heater. It will be appreciated that a heat conductive material may be heated by means other than electrical. The means may further comprise a temperature sensor, for example, but not strictly limited to a thermocouple. The range of temperature controllable and monitored by the means may extend from low to very high temperatures so as to permit selection of a temperature to optimise catalysis of the dissociation of the contaminant molecule.

Suitable solid-state species conductors will no doubt occur to the skilled addressee, examples of which may include but are not strictly limited to; for  $H^+$ ,  $CaZr_{0.9}In_{0.1}O_{3-x}$ ,  $BaZr_{0.9}Y_{0.1}O_{3-x}$ ,  $Ba_3Ca_{1.18}Nb_{1.82}O_{9-x}$ ,  $SrCe_{0.95}Yb_{0.05}O_{2.975}$  and for  $Ag^+$ , silver salts (for example, but not limited to, silver chloride). Other examples include, but are not strictly limited to; for  $H^+$ , organic membranes, inorganic membranes, polymer membranes and other commercially available species conductors (for example, but not limited to Nafion™ or Nasicon™);  $O^{2-}$ , yttrium stabilised zirconia (YSZ) and silver salts (for example, but not limited to, silver chloride).

To meet the requirements for monitoring contaminant species within the semiconductor processing environment it is necessary to identify a suitable sensing technology that is independent of the total pressure and that will provide a log-linear output signal in order to measure across a wide pressure range. In addition it is also necessary that the sensing material will not become depleted or otherwise affected by constant exposure to the reducing environment within the vacuum. The inventors have found that with suitable adaptation, solid-state electrochemical materials can meet these requirements.

The selection of the electrochemical solid-state electrolyte for such a sensor will depend upon the target contaminant gas of interest and in particular upon its dissociated ionic species. The electrolyte is selected to have properties that will enable it to conduct an ionic species of the target gas. Conduction of the ionic species will generate an electronic signal that can be measured to provide an indication of the quantity of contaminant gas within the monitored environment. In addition, to improve the selectivity of such a device it is extremely important to select a catalytic electrode material that will maximise the dissociation of the target contaminant gas to its ionic species (whilst minimising the dissociation of other species that are not of interest). To provide a calibrated output signal it is also necessary to provide a reference device that is matched to the concentration range of the contaminant gas to be measured thereby minimising any effect of the electrochemical semi-permeability of the electrolyte material. The reference device (of known concentration) is provided at a reference electrode and the concentration gradient across the electrochemical sensor (i.e. between the measurement and the reference electrode) is used to calculate the contaminant gas concentration at the measurement electrode.

Whilst the selection of materials for the construction of such a sensor is important it is also necessary to engineer the construction of the sensor in a manner that is compatible with installation into a vacuum environment. Considering the sensor will be placed within a vacuum environment that may have a pressure approximately 1 billion times less than atmospheric pressure (i.e. at  $1\text{e}^{-6}$  mbar) the proper design and construction of an effective vacuum seal for the sensor is essential. The vacuum seal is an extremely important part of any device intended for insertion into a vacuum environment and provides a leak-tight seal between the vacuum environment and the surrounding ambient environment. Manufacturing an effective seal is not a trivial matter and requires specific skills in order to seal metallic to ceramic materials and to allow for the feed-through of the necessary electrical connections whilst maintaining a leak-tight structure.

Finally, the mechanical design and construction of a sensor intended for use in vacuum environments is also important. The number of molecules within a vacuum environment is significantly lower than at atmosphere (i.e. approx. 1 billion times less at  $1\text{e}^{-6}$  mbar). In addition, the flow characteristics of residual gases in a vacuum environment are governed by probabilistic molecular flow mechanics. Hence, it is necessary to construct a vacuum sensor in such a manner that the sensing component design, construction and positioning is such to maximise interaction with the gaseous species of interest in the residual atmosphere."

Please amend pages 6-10 by deleting the following text beginning on page 6 line 10 through page 10 line 30 as follows:

~~In use the cell is used in conjunction with a device for measuring the electrical characteristics of the cell. For example, but without limitation, the device may be configured to measure the electrical current (in an amperometric configuration) or the emf (in a potentiometric configuration) produced across the cell.~~

~~Each electrode may be comprised from, or coated with, its respective catalyst. The "catalyst" electrode materials may be a metal, a conducting oxide or another suitable catalysing material. The selection of the electrode material will favour the dissociation of the species of interest whilst minimising the dissociation for permanent (ie not of interest) species. The skilled addressee will no doubt envisage appropriate catalysts for separating certain ionic species from certain molecules without departing from the invention. Without limitation,~~

catalysts may include platinum (for liberating  $H^+$  from water or  $O^{2-}$  from molecular oxygen), ruthenium (for liberating  $H^+$  from hydrocarbons), nickel, gold, silver or silver salts.

During use of the sensor, a reference environment with known quantities of the species is provided within the reference environment space. This is used as a reference with which the measured quantity of the species in the monitored environment contained in the monitored environment space can be compared. By applying a suitable algorithm incorporating measured parameters of the electrical signal generated by the cell and known characteristics of the reference environment, the partial pressure, and thus relative quantity of the species in the monitored environment can be calculated.

In circumstances where it would be relatively straightforward to provide a reference environment which contains, as the reference molecule, a known quantity of the same chemical species as the contaminant molecule, for example,  $O_2$ , the catalyst for the measurement electrode may conveniently comprise the same material as the catalyst for the reference electrode. However, where it would be relatively difficult to provide such a reference environment, for example, where the contaminant molecule is  $H_2O$ , depending on the chosen reference molecule the catalyst for the measurement electrode may comprise different material from the catalyst for the reference electrode. Even in this latter situation, the catalysts may still comprise the same material, for example platinum would be a suitable catalyst for the dissociation of  $H_2O$  as a contaminant molecule and for the dissociation of  $H_2$  as a reference molecule.

The reference environment space may be a sealed enclosure into which a controlled environment is provided. The source of ionic species provided in the reference environment may be a source of the contaminant molecule or any other source of that ionic species. The source may be provided in any physical phase, for example, but not limited to a gas, a liquid or a solid. For ease of storage and handling, a solid state source is preferable. Suitable solid state sources will no doubt occur to the skilled addressee. Examples of suitable reference environment sources include but are not strictly limited to a gas, a metal, a metal/metal hydride, a metal alloy/metal hydride, any solid hydrated species, any solid organic species (for  $H^+$ ) or copper/copper oxide ( $Cu_2O$ ), nickel/nickel oxide ( $NiO$ ) and chromium/chromium oxide ( $Cr_2O_3$ ) (for  $O^{2-}$ ).

~~Other suitable sources may include but are not limited to organic acids or liquid organic species (for  $H^+$ ).~~

~~The means for initiating the catalysis of the dissociation of the molecules preferably comprises means for controlling and monitoring the temperature of the cell. In the preferred embodiments, sealing means are provided for separating a reference environment space from a monitored environment space, the means for controlling the temperature of the cell including a heating device contained within the reference environment space. Thus, in a second aspect the present invention provides a contaminant molecule sensor configured for use in a vacuum environment, the sensor comprising an electrochemical cell comprising a measurement electrode coated with, or comprised from, a catalyst selected for its ability to catalyse the dissociation of a contaminant molecule into its ionic species, a reference electrode coated with, or comprised from, a catalyst selected for its ability to catalyse the dissociation of a reference molecule into its ionic species, and a solid state ionic species conductor bridging the measurement electrode and the reference electrode, the conductor being selected to conduct an ionic species common to the dissociated contaminant and reference molecules, means for controlling and monitoring the temperature of the cell, and sealing means for separating a reference environment space from a monitored environment space, the means for controlling and monitoring the temperature of the cell including a heating device contained within the reference environment space~~

~~The means for controlling and monitoring the temperature may include an electrically powered heater, for example a nichrome wire wound heater. It will be appreciated that a heat conductive material may be heated by means other than electrical. The means may further comprise a temperature sensor, for example, but not strictly limited to a thermocouple. The range of temperature controllable and monitored by the means may extend from low to very high temperatures so as to permit selection of a temperature to optimise catalysis of the dissociation of the contaminant molecule.~~

~~Suitable solid state species conductors will no doubt occur to the skilled addressee, examples of which may include but are not strictly limited to; for  $H^+$ ,  $CaZr_{0.9}In_{0.1}O_{3-x}$ ,  $BaZr_{0.9}Y_{0.1}O_{3-x}$ ,  $Ba_3Ca_{1-18}Nb_{1-82}O_{9-x}$ ,  $SrCe_{0.95}Yb_{0.05}O_{2.975}$  and for  $Ag^+$ , silver salts (for example, but not~~

~~limited to, silver chloride). Other examples include, but are not strictly limited to; for  $H^+$ , organic membranes, inorganic membranes, polymer membranes and other commercially available species conductors (for example, but not limited to Nafion<sup>™</sup> or Nasicon<sup>™</sup>);  $O^{2-}$ , yttrium stabilised zirconia (YSZ) and silver salts (for example, but not limited to, silver chloride).~~

~~To meet the requirements for monitoring contaminant species within the semiconductor processing environment it is necessary to identify a suitable sensing technology that is independent of the total pressure and that will provide a log linear output signal in order to measure across a wide pressure range. In addition it is also necessary that the sensing material will not become depleted or otherwise affected by constant exposure to the reducing environment within the vacuum. The inventors have found that with suitable adaptation, solid state electrochemical materials can meet these requirements.~~

~~The selection of the electrochemical solid state electrolyte for such a sensor will depend upon the target contaminant gas of interest and in particular upon its dissociated ionic species. The electrolyte is selected to have properties that will enable it to conduct an ionic species of the target gas. Conduction of the ionic species will generate an electronic signal that can be measured to provide an indication of the quantity of contaminant gas within the monitored environment. In addition, to improve the selectivity of such a device it is extremely important to select a catalytic electrode material that will maximise the dissociation of the target contaminant gas to its ionic species (whilst minimising the dissociation of other species that are not of interest). To provide a calibrated output signal it is also necessary to provide a reference device that is matched to the concentration range of the contaminant gas to be measured thereby minimising any effect of the electrochemical semi permeability of the electrolyte material. The reference device (of known concentration) is provided at a reference electrode and the concentration gradient across the electrochemical sensor (i.e. between the measurement and the reference electrode) is used to calculate the contaminant gas concentration at the measurement electrode.~~

~~Whilst the selection of materials for the construction of such a sensor is important it is also necessary to engineer the construction of the sensor in a manner that is compatible with installation into a vacuum environment. Considering the sensor will be placed within a~~



~~vacuum environment that may have a pressure approximately 1 billion times less than atmospheric pressure (i.e. at  $1e^{-6}$  mbar) the proper design and construction of an effective vacuum seal for the sensor is essential. The vacuum seal is an extremely important part of any device intended for insertion into a vacuum environment and provides a leak tight seal between the vacuum environment and the surrounding ambient environment. Manufacturing an effective seal is not a trivial matter and requires specific skills in order to seal metallic to ceramic materials and to allow for the feed through of the necessary electrical connections whilst maintaining a leak tight structure.~~

~~Finally, the mechanical design and construction of a sensor intended for use in vacuum environments is also important. The number of molecules within a vacuum environment is significantly lower than at atmosphere (i.e. approx. 1 billion times less at  $1e^{-6}$  mbar). In addition, the flow characteristics of residual gases in a vacuum environment are governed by probabilistic molecular flow mechanics. Hence, it is necessary to construct a vacuum sensor in such a manner that the sensing component design, construction and positioning is such to maximise interaction with the gaseous species of interest in the residual atmosphere.~~